The Role of Active Locomotion in Space Perception[*]

Naohide Yamamoto[†]
Cleveland State University

Abstract: It has been shown that active control of locomotion increases accuracy and precision of nonvisual space perception, but psychological mechanisms of this enhancement are poorly understood. The present study explored a hypothesis that active control of locomotion enhances space perception by facilitating crossmodal interaction between visual and nonvisual spatial information. In an experiment, blindfolded participants walked along a linear path under one of the following two conditions: (1) They walked by themselves following a guide rope; and (2) they were led by an experimenter. Subsequently, they indicated the walked distance by tossing a beanbag to the origin of locomotion. The former condition gave participants greater control of their locomotion, and thus represented a more active walking condition. In addition, before each trial, half the participants viewed the room in which they performed the distance perception task. The other half remained blindfolded throughout the experiment. Results showed that although the room was devoid of any particular cues for walked distances, visual knowledge of the surroundings improved the precision of nonvisual distance perception. Importantly, however, the benefit of preview was observed only when participants walked more actively. This indicates that active control of locomotion allowed participants to better utilize their visual memory of the environment for perceiving nonvisually encoded distance, suggesting that active control of locomotion served as a catalyst for integrating visual and nonvisual information to derive spatial representations of higher quality.
Keywords: space perception, locomotion, visual memory, crossmodal interaction

1. Introduction

Actively controlling locomotion enhances space perception. Philbeck et al. (2001) provided one example by asking blindfolded participants to walk along a triangular path and come back to the starting position (triangle completion task). In one condition, an experimenter led participants along two legs of a triangle and released them at the end of the second leg. Participants then walked the third leg toward the starting position. In another condition, participants were given a cue indicating the end of the second leg, but released at the end of the first leg – that is, they walked both the second and third legs actively. Participants were able to return to the starting position with greater accuracy and precision in the latter condition, even though they had to walk a longer distance without assistance. Results like this suggest that perception of self-motion can be enhanced by active locomotion. Although similar findings have been made in the literature (e.g., Rieser 1999), psychological mechanisms that give rise to this enhancement are poorly understood. The present study addressed this issue by exploring the hypothesis that active locomotion enhances space perception by facilitating crossmodal interaction between visual and nonvisual spatial information.

This hypothesis has been formulated on the basis of observations that when space perception was enhanced by active locomotion, participants were typically allowed to view an environment beforehand (e.g., Philbeck et al. 2001; Philbeck and O'Leary 2005). Although the

---

[*] This is a postprint of an article that has been published in *Cognitive Processing* (August 2012, vol. 13, pp. S365-S368, doi: 10.1007/s10339-012-0462-z). The final publication is available at www.springerlink.com.

[†] Please address correspondence concerning this article to Naohide Yamamoto, Department of Psychology, Cleveland State University, 2121 Euclid Avenue, Cleveland, OH 44115, USA. Email: n.yamamoto@csuohio.edu

primary purpose of this preview was to have participants view a target that they would subsequently navigate to without vision using active walking, it also provided them with general visual information about the environment. Thus, it is possible that this visual knowledge played a role in the observed enhancement of space perception. However, it has also been shown that having visual knowledge about surroundings alone does not always increase the accuracy or precision of nonvisual space perception. In the triangle completion task, for example, performance was not altered by environmental preview when visual cues did not specify to-be-walked paths (i.e., when participants still had to be guided after previewing the environment; Philbeck et al. 2001). Together, these findings indicate that visual knowledge of the surroundings is not sufficient for the enhancement of nonvisual space perception to take place. Rather, it is suggested that enhanced space perception results from the interaction between active locomotion and visual knowledge.

To test this hypothesis, in the present study blindfolded participants were asked to walk along linear paths with or without a preview of an environment and indicate the walked distance by tossing a beanbag to the starting position (Sahm et al. 2005). They walked either passively by being guided by an experimenter (passive walking) or actively by independently following a guide rope (active walking). It was predicted that the benefit of the preview (i.e., enhanced perception of walked distances) would be observed only in the active walking condition.

2. Method

2.1 Participants

Forty participants (20 males and 20 females, mean age = 23.81 years) volunteered in return for monetary compensation or partial credit in psychology courses at Cleveland State University. They reported normal or corrected-to-normal vision.

2.2 Materials

The experiment took place in a 5.6 × 7.7 m laboratory. Room walls were covered with black ceiling-to-floor curtains and the floor had no discernible patterns. Linear paths walked by participants were parallel to the two long walls. In the passive walking condition, the room contained no objects but a measuring tape that was laid parallel with the walked paths, approximately 50 cm away from them. The tape was extended from wall to wall, providing no specific cues for walked distances. In the active walking condition, a wall-to-wall guide rope was placed above the measuring tape at the height of participants' waist. They held onto this rope while walking with their nondominant hand, on which they wore a cotton glove for protection. The rope was extended tightly so that it allowed little veering. The beanbag approximately measured 10 cm in length and weighed 150 g. Hearing protectors (noise reduction rating = 21 dB) were worn by participants during the experiment to reduce the influence of auditory cues.

2.3 Design and Procedure

Factorial combination of walking (passive or active) and visual (preview or no preview) conditions formed four groups, and participants were randomly assigned to them with the constraint that each group had five males and five females. In the preview condition, participants briefly viewed the laboratory before beginning to walk in each trial. In the no preview condition, they remained blindfolded throughout the experiment. An experimenter met with participants in the first floor of the building in which the laboratory was located. Participants first practiced tossing the beanbag to visible targets on the ground. They were then blindfolded and guided to the laboratory, which was in the second floor. They followed a circuitous path that contained multiple turns, and thus had no clear idea about where they were in the building when placed at the starting position in the laboratory. From this position, they walked along linear paths of 1-6 m either by being led by the experimenter or by following the guide rope until they felt a tactile marker attached to the rope at an appropriate distance. The marker was absent when participants viewed the environment in the preview condition. Upon stopping at the end of each path, they turned around and tossed the beanbag underhand with their dominant hand so that it would land directly at the starting position. No error feedback was given, and participants were guided back to the starting position for the next trial. They first walked 3-m and 5-m paths, once apiece, to become familiar with the procedure. Subsequently, they walked paths of 2, 4, and 6 m, five times apiece, in random order. In addition, filler trials using 1-m paths were randomly intermixed with the experimental trials in order to increase the variability of stimulus distance. Data from practice and filler trials were not included in analyses.

In addition to the primary distance perception task, in each trial participants were given a five-digit random number and asked to repeat it back to the experimenter after tossing the beanbag. This number was typically retained through rehearsal, and thus this concurrent task was intended to interfere with subvocal pace-counting while walking. Participants' performance in beanbag tosses was not analyzed as a function of accuracy in recalling this number because it was generally good in all conditions (mean accuracy = 98%).

2.4 Data Analysis

The endpoint of each path and the point at which the beanbag landed were perpendicularly projected onto the measuring tape, and the distance between them was measured as an indicator of perceived walked distance in each trial. The beanbag was generally thrown in parallel with the measuring tape, and thus this method did not result in any significant underestimation of the actual distance over which the beanbag was tossed. Three types of errors in beanbag tosses were calculated from these data. *Signed* error was obtained by subtracting the actual stimulus distance from the perceived distance for a given trial. Because positive and negative signed errors can cancel out by averaging, *absolute* error was also derived from signed error. Signed and absolute errors represent participants' accuracy in distance perception. In order to characterize participants' precision (i.e., variability) in distance perception, *variable* error was defined as the standard deviation of five responses for a given stimulus distance. These errors were analyzed separately by analyses of variance (ANOVAs) with walked distance (2, 4, and 6 m) as a within-subject factor and walking condition (passive or active) and visual condition (preview or no preview) as between-subject factors. However, in the interest of brevity, only variable error data are reported in this article. Note that when space perception was enhanced by active locomotion or visual knowledge in previous studies, the enhancement often appeared in the form of increased precision (e.g., Philbeck et al. 2001; Philbeck and O'Leary 2005).

It was hypothesized that the benefit of preview would be present only in the active walking condition. In the omnibus ANOVA, this would be assessed by the interaction between walking and visual conditions. However, even if this interaction were significant, it would not necessarily be relevant to the hypothesis because it could be supported only by a specific form of the interaction (i.e., no difference between preview and no preview conditions when participants walked passively, and significantly smaller error in the preview condition than in the no preview condition when they walked actively). Thus, more direct tests of the hypothesis were carried out by examining simple main effects of visual condition within each of the walking conditions.

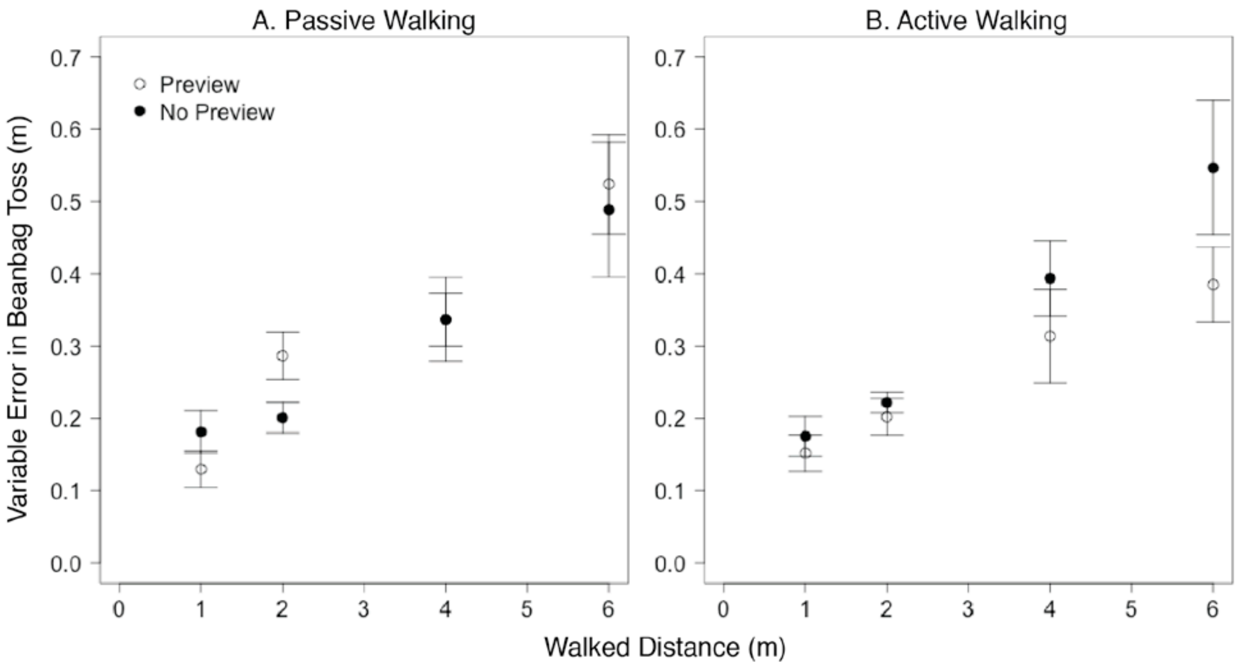

Figure 1. Mean variable errors in beanbag tosses as a function of walked distance, walking condition, and visual condition. Error bars represent ±1 standard error of the mean.

3. Results and Discussion

Mean variable errors in beanbag tosses are plotted in Figure 1 as a function of walked distance, walking condition, and visual condition. When participants walked passively by being guided by an experimenter, their perception of walked distance was not altered by the preview of the laboratory (Figure 1A). On the other hand, when they walked more actively by following a guide rope, viewing the laboratory beforehand increased the precision of distance perception (Figure 1B). Consistent with these observations, the interaction between walking and visual conditions was marginally significant in the omnibus ANOVA, $F(1, 36) = 3.47$, $p = .071$, $\eta_G^2 = .034$. More importantly, the simple main effect of visual condition was absent in the passive walking condition but present in the active walking condition, $F < 1$ and $F(1, 18) = 4.54$, $p = .047$, $\eta_G^2 = .063$, respectively. In addition to these major findings, Figure 1 also showed that variable error increased as participants walked farther. The main effect of walked distance was significant, $F(1, 36) = 21.80$, $p < .001$, $\eta_G^2 = .28$. All other main effects and interactions did not reach statistical significance, *F*s < 1.

These findings supported the hypothesis that enhanced space perception results from an interaction between active locomotion and visual knowledge of surroundings. Neither active locomotion nor visual knowledge was sufficient to alter perception of walked distance by itself, as shown by the lack of main effects for walking and visual conditions. Instead, precision of perceived distance was increased only when both of these factors were present.

Importantly, enhancement of distance perception was observed in the active walking condition, even though previewing the laboratory did not provide participants with any specific information about to-be-walked distances. This helps disentangle effects of preview and foreknowledge of where to walk (Philbeck et al. 2001). Because the laboratory was devoid of cues that specified walked distances, increased precision of distance perception following the preview most likely stemmed from the benefit of having visual knowledge about the surroundings itself. However, as discussed above, this knowledge exerted its effect only when it was coupled with active walking.

Together, these findings suggest that one role of active locomotion in space perception is to facilitate interaction between (nonspecific) visual information about surroundings and nonvisual information about body movements. In other words, nonvisual spatial information derived from actively controlled locomotion appears to interact more effectively with visual information about the environment, and in turn, this facilitated crossmodal interaction leads to higher quality spatial representations. Further research is needed to investigate the actual mechanisms that underlie this facilitation, but the present findings indicate that it is a promising approach toward fully understanding why space perception is enhanced by active locomotion.

Acknowledgments

This research was supported in part by Cleveland State University Research and Creative Achievement Award. The author thanks Adam Woods for comments on a draft of this article, and Dagmara Mach, Govind Sailesh Pappu, Lucinda Rohde, and Jessica Willesch for assistance with data collection.

References

Philbeck JW, Klatzky RL, Behrmann M, Loomis JM, Goodridge J (2001) Active control of locomotion facilitates nonvisual navigation. J Exp Psychol Hum Percept Perform 27:141-153. doi: 10.1037/0096-1523.27.1.141

Philbeck JW, O'Leary S (2005) Remembered landmarks enhance the precision of path integration. Psicológica 26:7-24.

Rieser JJ (1999) Dynamic spatial orientation and the coupling of representation and action. In: Golledge RG (ed) Wayfinding behavior: Cognitive mapping and other spatial processes. Johns Hopkins University Press, Baltimore, pp 168-190

Sahm CS, Creem-Regehr SH, Thompson WB, Willemsen P (2005) Throwing versus walking as indicators of distance perception in similar real and virtual environments. ACM Trans Appl Percept 2:35-45. doi: 10.1145/1012551.1012600